An Approach to Parallel Parking and Zero Turning Radius in Automobiles

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Abstract—Conventional steering mechanism involves either the use of Ackerman or Davis steering systems. The disadvantage associated with these systems is the minimum turning radius that is possible for the steering action. This difficulty that is associated with the conventional methods of steering is eliminated by employing a four wheel steering system. In this system, the wheels connected to the front axles are turned opposite to each other, and so are the wheels connected to the rear axle. The wheels on the on left half vehicle rotate in one direction and the ones on the right half of the vehicle rotate in the opposite direction. This arrangement of the wheels enables the vehicle to turn 360 degrees, without moving from the spot, i.e. the vehicle has zero turning radius. This helps in maneuvering the vehicle in tight spaces such as parking lots and within small compounds.

Index Terms— Steering mechanism, turning radius, parallel parking

I. INTRODUCTION

The various functions of the steering wheel are, to control the angular motion the wheels; direction of motion of the vehicle, to provide directional stability of the vehicle while going straight ahead, to facilitate straight ahead condition of the vehicle after completing a turn , the road irregularities must be damped to the maximum possible extent. This should co-exist with the road feel for the driver so that he can feel the road condition without experiencing the effects of moving over it.

A. Types of Steering

The most frequently used type of steering, are using the front two wheels of the vehicle. This type of steering suffers from the comparatively larger turning circle and the extra effort required by the driver to negotiate the turn. Some types of industry battery trucks and industry backhoe loaders use this type, where only the two rear wheels control the steering. It can produce smaller turning circles, but is unsuitable for high speed purposes and for ease of use. Many modern cars use rack and pinion steering mechanisms. The rack and pinion design has the advantages of a large degree of feedback and direct steering "feel". The recirculating ball mechanism is a variation on the older worm and sector design; the steering column turns a large screw (the "worm gear") which meshes with a sector of a gear, causing it to rotate about its axis as the worm gear is turned; an arm attached to the axis of the sector moves the Pitman arm, which is connected to the steering linkage and thus steers the wheels. At either end of the apparatus the balls exit from between the two pieces into a channel internal to the box which connects them with the other end of the apparatus, thus they are "recirculated". Power steering assists the driver of an automobile in steering by directing a portion of the vehicle's power to traverse the axis of one or more of the road wheels. As vehicles have become heavier and switched to front wheel drive, particularly using negative offset geometry, along with increases in tyre width and diameter, the effort needed to turn the steering wheel manually has increased – thus power steering systems have been developed. There are two types of power steering systems—hydraulic and electric/electronic. A hydraulic-electric hybrid system is also possible. An outgrowth of power steering is speed adjustable steering, where the steering is heavily assisted at low speed and lightly assisted at high speed.

The most effective type of steering, this type has all the four wheels of the vehicle used for steering purpose. A detailed description of this type follows.

II. FOUR WHEEL STEERING

Contemporary rear axles allows for coincidental steering through the influence of variation of elasto-kinematic steering; rear wheels rotate, due to an influence of variation of vertical load of wheels (tilting), in the same direction as front wheels. Nevertheless, such a turn of rear wheels is very small and driver's will-independent. A disadvantage of this so-called passive steering system is that it operates even when driving in straight direction when single wheel of an axle hits surface irregularity (deterioration of directional stability). Therefore, the active system means that rear wheels are possible to be turned either coincidently or non-coincidently. The increase of the maneuverability when parking the vehicle is achieved by means of disconcordant steering, meanwhile the increase of the driving stability at higher speeds is achieved through concordant steering.

In a typical front wheel steering system, the rear wheels do not turn in the direction of the curve, and thus curb on the efficiency of the steering. Normally, this system has not been the preferred choice due to the complexity of conventional mechanical four wheel steering systems. However, a few cars like the Honda Prelude, Nissan Skyline GT-R have been available with four wheel steering systems, where the rear wheels turn by a small angle to aid the front wheels in steering. However, these systems had the rear wheels steered by only 2 or 3 degrees, as their main aim was to assist the front wheels rather than steer by themselves.

With advances in technology, modern four wheel steering systems boast of fully electronic steer-by-wire systems, equal steer angles for front and rear wheels, and sensors to monitor the vehicle dynamics and adjust the steer angles in real time. Although such a complex 4WS model has not been created for production purposes, a number of experimental concepts with some of these technologies have been built and tested successfully.

Two modes are generally used in these 4WS models:

A. Slow Speed – Rear Steer Mode

At slow speeds, the rear wheels turn in the direction opposite to the front wheels. This mode becomes particularly useful in case of pick-up trucks and buses, more so when navigating hilly regions. It can reduce the turning circle radius by 25% and can be equally effective in congested city conditions, where U-turns and tight streets are made easier to navigate.

B. High Speed

In high speeds, turning the rear wheels through an angle opposite to front wheels might lead to vehicle instability and is thus unsuitable. Hence, at speeds above 80 kmph, the rear wheels are turned in the same direction of front wheels in four-wheel steering systems.

For a typical vehicle, the vehicle speed determining the change of phase has been found to be 80kmph. The steering ratio, however can be changed depending on the effectiveness of the rear steering mechanism, and can be as high as 1:1.

Zero Turning Radius – 360 Mode

In addition to aforementioned steering types, a new type of four wheel steering was introduced by the concept vehicle Jeep Hurricane, one that could significantly affect the way our vehicles are parked in the future. This vehicle has all three modes of steering described above, though it sports a truly complex drive train and steering layout, with two transfer cases, to drive the left and right wheels separately. The four wheels have a fully independent steering and need to run in an unconventional direction to ensure that the vehicle turns around on its own axis.

III. DESIGN OF FOUR WHEEL STEERING SYSTEM

It is to be remembered that both the steered wheels do not turn in the same direction, since the inner wheels travel by a longer distance than the outer wheels.

A. Ackermann Steering Mechanism

Ackermann steering geometry is a geometric arrangement of linkages in the steering of a car or other vehicle designed to solve the problem of wheels on the inside and outside of a turn needing to trace out circles of different radii. The steering pivot points are joined by a rigid bar called the tie rod which is also a part of the steering mechanism. With perfect Ackermann, at any angle of steering, the centre point of all of the circles traced by all wheels will lie at a common point.

Modern cars do not use pure Ackermann steering, partly because it ignores important dynamic and compliant effects, but the principle is sound for low speed maneuvers, and the right and left wheels do not turn by the same angle, be it any cornering speed. We chose to use a simple control circuit to demonstrate the effectiveness of a four wheel steering system, and at the same time, simulated the suspension-steering assembly of a typical car to predict the Ackerman angles for corresponding steer angles. The design calculation for the model follows shortly

B. Condition for True Rolling Motion

Perfect steering of the wheels can be achieved only when all four wheels are rolling perfectly for all dynamic conditions. While tackling a turn, the condition of perfect rolling motion will be satisfied if all the four wheel axes when projected at one point called the instantaneous center, and when the following equation is satisfied:

$$\cot\phi - \cot\theta = c/b \qquad (1)$$

It is seen that the inside wheel is required to turn through a greater angle than the outer wheel. The larger the steering angle, the smaller the turning circle. It has been found that the steering angle can have a maximum value of about 44 degrees under dynamic conditions. The extreme positions on either side are called lock positions. The diameter of the smallest circle which the outer front wheel of the car can traverse and obtained when the wheels are at their extreme positions is known as the turning circle.

C. Benefits of Four Wheel Steering

With the 360^0 mode, the vehicle can quickly turn around at the press of a button and a blip of the throttle. Complicated three-point steering maneuvers and huge space requirements to park the vehicle are entirely phased out with this.

Crab mode helps simplify the lane changing procedure.

In conjunction with rear steer mode, four-wheel steering can significantly improve the vehicle handling at both high and low speeds.

Due to the better handling and easier steering capability, driver fatigue can be reduced even over long drives.

The only major restriction for a vehicle to sport four-wheel steering is that it should have four or more wheels. Hence, every kind of private and public transport vehicle, be it cars, vans, buses, can benefit from this technology.
Military reconnaissance and combat vehicles can benefit to a great extent from 360 mode, since the steering system can be purpose built for their application and are of immense help in navigating difficult terrain.

IV. CONSTRUCTION AND FUNCTION

The main components of a Honda 4WS system are the front steering gearbox, which turns the front wheels, the rear steering gearbox, which turns the rear wheels, and the center steering shaft, which links the two gearboxes. When the steering wheel is turned, the front wheels are steered in the same way as with a 2WS system. A rack-and-pinion mechanism in the front steering gearbox transmits this movement to the rear steering gearbox via the center shaft. (The rack-and-pinion mechanism is separate from the one to which the steering wheel is connected.) Via the rear tie rods, the rear steering gearbox steers the rear wheels by the appropriate angle and in the appropriate direction.

A. Steering Of Rear Wheels

When the steering wheel is turned from its straight-ahead position by an angle of 120 degree or smaller, the 4WS system performs to increase in-phase steering of the rear wheels angle.
When the steering wheel angle exceeds 120 degree, the rear wheels gradually straighten up then turn in the opposite direction.

B. Parallel Parking

The car requires just about the same length as itself to park in a spot. Also since the 360^0 mode doesn't require steering inputs the driver can virtually park the vehicle without even touching the steering wheel. All he has to do is give throttle and brake inputs, and even they can be automated in modern cars. Hence such a system can even lead to vehicles that park by themselves.

V. DESIGN AND ANALYSIS

A. Line Diagram of the Prototype

A line diagram of the prototype was prepared, as shown in Fig. 1, which indicates the linear dimensions of the prototype, as well as the instantaneous centre of the body, when the wheels are inclined in the required position for 360° rotation.

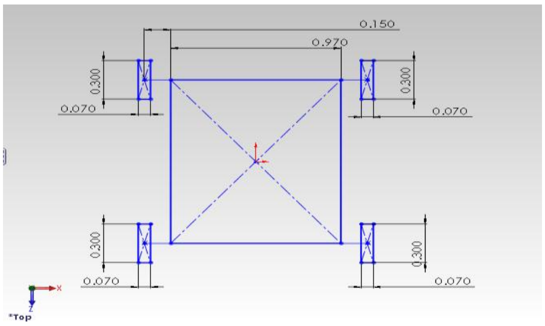

Fig. 1 Dimensions of Prototype

The dimensions of the prototype were measured to be as given below:

Wheelbase	= 0.970m
Track-width	= 0.970m
Frame length	= 0.900m
Frame width	= 0.910m

Distance of Instantaneous Centre from rear left wheel
= 3.78m

As evident from the figure, the instantaneous centre falls at the geometric centre of the prototype, and as a result, the path of the wheels, trace a circular path. The lines produced from the inclined wheels meet at the centre.

The steer angles for the inner and outer wheels during normal steering operation were also obtained, as seen below in Fig. 2.

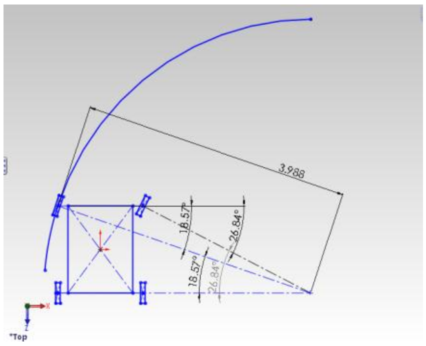

Fig. 2 Steer Angles for Inner and Outer Wheels

B. Analysis Procedure

The axis of the rear wheels were produced to either side of the vehicle. The steering was then turned to achieve maximum steer condition, and the axis of the front wheels were produced backwards.
The axis of the front left wheel and the front right wheel met at a point on the rear wheel axis produced towards one side, 3.78 m from the left wheel.
This was obtained while measuring the conformity of the steering system with Ackermann's condition for stability.
The inner wheel's steering angle was measured to be θ = 26.84°, and that of the outer steering wheel as φ = 18.57°.
The stability conditions for the mechanism confirm to Ackermann's conditions.

The average steering angle was calculated as

$(\varphi+\theta)/2 = (18.6+26.8)/2 = 22.7°$

The outer wheel turning radius was calculated as

$\sqrt{x^2+l^2} = \sqrt{3.78^2+1.27^2} = 3.98$ m

x = distance from point of intersection of front wheels on rear wheel axle produced to left rear wheel

l = wheel base of prototype

The inner wheel turning radius was calculated as

$\sqrt{(x-w)^2+l^2} = \sqrt{(3.78-1.27)^2+1.27^2} = 2.81$m

w = track width of prototype

C. Proof of Stability of the System

The condition for stability of a vehicle having Ackermann Steering Mechanism incorporated in it is given by the relation $\cot\phi - \cot\theta = w/l$

The w/l ratio of the prototype is 1.27 /1.27 = 1.

$\cot\varphi - \cot\theta = \cot 18.6 - \cot 26.8 = 1.000360$

Thus, we can see from above that the equation

$\cot\phi - \cot\theta = w/l$ is satisfied and hence the prototype is stable under Ackermann steering condition.

D. Time Analysis

The time taken for both - 360° steering mechanism and normal steering mechanism for two operations were recorded.

The first operation was parallel parking and the second was the turning of the vehicle in 3600.

The obtained readings are as follows:

Table 1

	Time Taken for 360^0 Mechanism	Time Taken for Normal Steering Mechanism
Parallel Parking	45 seconds	116 seconds
360^0	21 seconds	188 seconds

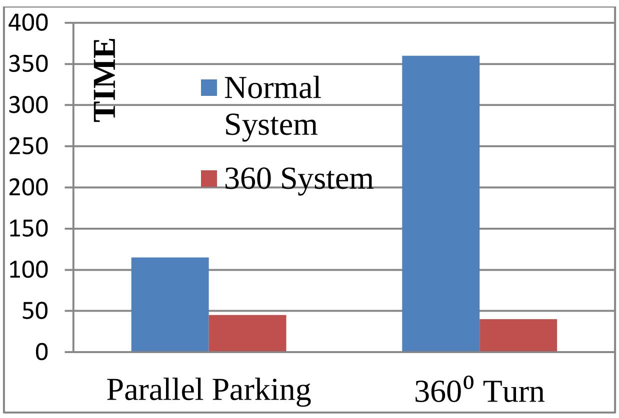

Fig. 3 Time Analysis

As clearly seen from the tabulated values (Table 1) and the graph (Fig 3), the 360° steering system has considerable advantage over the normal steering system in terms of time consumed for the operation. This is more so in the case where the vehicle is to turn 360^0.

And so, from the above values we can say that the 360^0 steering system is advantageous and saves a nominal amount of time, in maneuvering the vehicle in tight spaces, such as parking lots, and simplifies the process of parallel parking.

VI. Conclusion

A vehicle featuring low cost and user friendly steering mechanism has been introduced. This paper focused on a steering mechanism which offers feasible solutions to a number of current maneuvering limitations. A prototype for the proposed approach was developed by introducing separate mechanism for normal steering purpose and 3600 steering purpose. This prototype was found to be able to be maneuvered very easily in tight spaces, also making 360^0 steering possible.

Different mechanisms were adopted by trial and error method, in order to facilitate the engagement of the wheels in the required direction, and the most convenient method was adopted.

The time analysis, for the time required to perform a parallel parking maneuver and a 360^0 turn was carried out, and it was established that the implementation of the modification, led to decrease in the time required for the performance of the above operations.

The prototype was tested to ensure the conformity with Ackermann's steering condition, and it complied with the same.

The forces acting on each wheel was obtained and the force that required to be applied on the steering wheel, in order to engage the wheels in the required direction was calculated.

The features that enhanced the prototype were the increase in maneuverability in limited space, and the parallel parking ability. The disadvantages associated with the current prototype were the need to pull two different levers to engage the system, and the space constraints for incorporating the system.

References

[1] Dr. N. K. Giri, "Automotive Mechanics", Khanna Publishers, 2-B, Nath Market, Nai Sarak, New Delhi – 111006. (1996) , 7th Edition

[2] Heinz Heisler, "Advanced Vehicle Technology" Second edition.

[3] College of technology, PSG, "Design data – data book of engineers" published by Kalaikathir Achchagam.

[4] Rattan S, "Theory of machines", Khanna publications.

[5] Thomas. D. Gillespie, "Fundamentals of Vehicle Dynamics", Society of Automotive Engineers, Warrendale. (2000) Online Edition

[6] (Automobile Engineering), Madras Institute of Technology, guided by Dr. P.Mannar Jawahar

[7] Hiroshi Ohmura (1990) 'Rear wheel steering apparatus', Mazda Motor Corporation, U.S patent No. 4,953,648